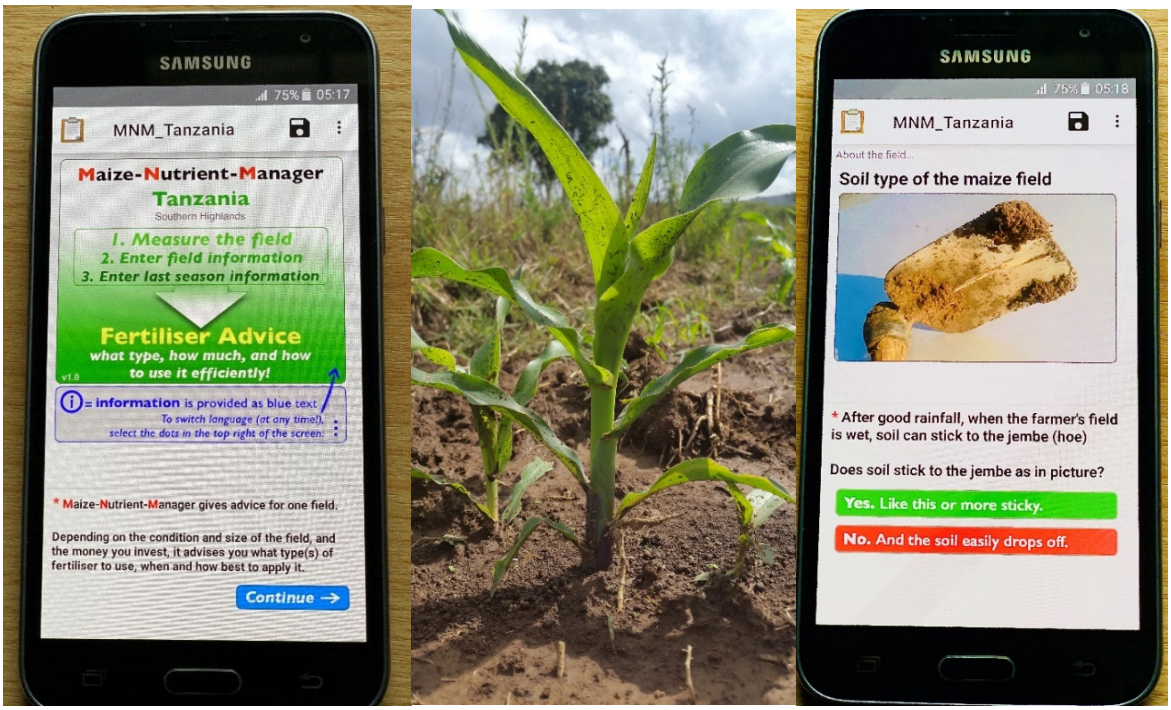
Internship Report: Laying the foundation of the Maize Nutrient Manager (MNM) mobile phone-based App in the Southern Highlands of Tanzania.

Internship- Plant Production Systems



Mukoma Kilakila

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WAGENINGEN
UNIVERSITY & RESEARCH

Laying the foundation of the Maize Nutrient Manager (MNM) mobile phone-based App in the Southern Highlands of Tanzania.

Internship Plant Production Systems

Name Student:	*Mukoma Kilakila*
Registration Number:	*900103435010*
Study:	*MSc Organic Agriculture – Specialization Agroecology*
Chair group:	*Plant Production Systems (PPS)*
Code Number:	*PPS-70427*
Date	*February, 2020*
Supervisors:	*Jens Andersson*
	Renske Hijbeek
Examiners:	*Martin van Ittersum*

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Acronyms and abbreviation

DST	Decision Support Tool
CIMMYT	The International Maize and Wheat Improvement Center
MNM App	Maize Nutrient Manager advisory mobile phone app
SSA	Sub-Saharan Africa
TARI	Tanzania Agriculture Research Institute
TAMASA	Taking Maize Agronomy to Scale in Africa project
WUR	Wageningen University and Research
FUE	Fertilizer Use Efficiency

Acknowledgement

I would like to thank my supervisors, dr. Jens Andersson of CIMMYT and dr. Renske Hijbeek at Wageningen University and Research (WUR) for their unfailing support throughout the project, and the Tanzania Agriculture Research Institute (TARI) team at Uyole Research Centre for the close collaboration and support on the ground. Thanks to extension workers of Mbozi and Momba districts who at all times accompanied and facilitated the meetings with farmers for interviews in most of the villages. Time and energy, they dedicated to this great work, were enormous. Finally, I would like to express my extraordinary gratitude to the farmers of the study area for their willingness, time, and active participation in the interviews and making this study success at least so far.

Abstract

Maize remains one of the most important cereal crops grown in small-holder farming systems in sub-Saharan Africa (SSA)(Cairns et al., 2013). Its cultivation is generally characterized by limited input use and low yields. The low yields are often associated with low soil fertility, pest, and diseases, weeds, low and inappropriate use of inputs such as fertilizers (Sanchez, 2002). This internship aimed to develop a nutrient management advice protocol that was used to inform the development of Maize nutrient Manager (M-N-M) advisory mobile phone app for maize farmers and extension workers in the Southern Highlands of Tanzania. The MNM app advises farmers what type of fertilizer to use, when, and how best to apply it depending on the conditions of the field to improve maize yield.

The study was conducted in two districts of Mbozi and Momba in the Songwe region, and three groups of respondents were identified to which interviews were carried out. The first group consisted of smallholder maize farmers. The second was a group of agro-dealers who supplied agricultural inputs to maize farmers in the two districts and the last group composed of extension workers serving the districts. To reach the aim of the study I carried out interviews with farmers, agro-dealers and extension workers with the objectives of (i) investigating the diversity in fertilizer management practices across smallholder maize farmers(ii) investigating the kind of advice extensionists provide to farmers regarding fertilizer use (iii) investigating availability, price, and standard packages of fertilizer and other inputs such as seeds and herbicides in Mbozi and Momba districts.

The data collected through the ODK survey (n=102) showed that there is room for farmers to improve their management practices to reach higher yield maize production. The most critical area that needs much improvement or attention is the timing of application of both basal and top-dressing fertilizers. The Nutrient management advice protocol informed the MNM app to advise the farmer to; continue crop rotate maize with legumes(groundnuts and beans), use manure regularly, apply available basal P fertilizer at planting or immediately after seed emergence(in case of dry planting), apply appropriate amount of N fertilizer first at 5-6 leaves and then at 8-10 leaves(split application). In the situation of a little number of available N fertilizers, farmers could apply all at once when the maize plants reach 7-8 leaves.

The findings of the study revealed research questions that need further investigation in the area; 1. Investigate the socio-economic and agronomic constraints that hindered farmers from adopting the best fertilizer use practices. 2. Further investigation on the use of manure in the area from management to application. 3. Investigate further the adoption of MNM app among farmers.

1. Introduction

Maize remains one of the most important cereal crops grown in small-holder farming systems in sub-Saharan Africa (SSA). Its cultivation is generally characterized by limited input use and low yields (Cairns et al., 2013). The low yields are often the results of low soil fertility, pest, and diseases, weeds, low and inappropriate use of inputs such as fertilizers(Sanchez, 2002). To keep pace with the increase in food demand due to a growing population in Sub-Saharan Africa which is projected to double from a current population of 1.3 billion people by 2050 (World Population Prospects, 2019) yields of major staple crops including maize will need to increase. The adoption of best agronomic practices by farmers with efficient fertilizer use is more likely to increase yields of cereal crops (Ichami et al., 2018).

Challenges associated with the use of inorganic fertilizers in much of SSA in maize production are the low rates of application and the lack of fertilizer recommendations tailored to field conditions and farmer management practices (Wortmann et al., 2018). The fertilizer recommendations in SSA (Fixed types and quantities per crop) are commonly given at the level of the agro-ecological zone or administrative district (Ichami et al., 2018). For example, in the Southern Highlands of Tanzania, the recommendations for maize crop is 120kg of **N** and 20 kg of **P** at the regional level. However, field conditions such as soil fertility and nutrient management practices vary among smallholder farmers in the same region (Tittonell et al., 2005). As a result, the blanket fertilizer recommendations often fail to deliver yield expectation of farmers after the use of fertilizer (Tittonell et al., 2013). As fertilizer is an expensive commodity; farmers expect high returns on their investment at low risk. Therefore, to reach these high returns farmers' fertilizer use decisions need to be supported with good advice as to maximize net returns to nutrient applied (Wortmann et al., 2018).

In SSA agricultural extension agents play an essential role in providing farmers with advice on fertilizer use and other agronomic practices. Nevertheless, extension agents promote blanket fertilizer recommendation, without adapting to the local conditions of the field and the farmer(Belay & Abebaw, 2004). For instance, blanket fertilizer recommendation can well respond to nutrient deficiencies related to soil type, but not deficiencies related to cropping history and management, which differ from one farmer to the other within the same region (Vanlauwe et al.,2006). The diversity in nutrient management practices, soil fertility, cropping history, the financial status of the farmer requires advice adapted to field condition and farmer context.

This internship focused on developing advice protocols that can be incorporated into the Maize-Nutrient-Manager (MNM) advisory mobile phone app, which could be used as DST for maize farmers and extension workers in Southern Highlands of Tanzania. MNM advises farmers what type of fertilizer to use and when and how best to apply it, depending on the conditions of the field and the money the farmer is willing to invest. To develop the advice protocols, I carried out interviews with farmers, agro-dealers and extension workers with the objective of (i) investigating the diversity in fertilizer management practices among maize

farmers(ii) investigating the kind of advice extensionists currently provide to farmers regarding fertilizer use (iii) investigating availability, price, and standard packages of fertilizer and other inputs such as seeds and herbicides. My work focused on the Mbozi and Momba districts of Songwe region in the Southern Highlands of Tanzania.

Information from farmers was collected through interviews and ODK surveys. Figures and tables show the results of these ODK collected data.

The rest of this report is organized into three chapters. Chapter 2 gives an overview of the material and methods used throughout the study. Chapter 3 presents the results of the study and offers some implications/recommendations for MNM advisory app and further analysis. The implications for MNM advisory app design are presented in the Result chapter (3) immediately following the findings of my work. Chapter 4, the final, offers a brief discussion on findings and draws some important conclusions and recommendations for further research questions in the area.

2. Material and Methods

2.1 Study area

The study was conducted in two districts of Mbozi and Momba in the Songwe region. The region of Songwe is part of the Southern Highlands of Tanzania, which borders Zambia and Malawi (Fig. 1). Songwe region is located between latitude 7^0 to 11.5^0 S and longitude 30^0 and 38^0 E and at 1261m above sea level. The climate of the region is tropical characterized by a unimodal rainfall pattern with an average annual rainfall of 1577 mm occurring from November to May. The average annual temperature is 20.8^0C, with a maximum temperature of 22.8^0C in November and July being the coldest month with a temperature of 18.3^0C (Climate-data.org, 2020). The soils of the Southern Highlands region of Tanzania are quite diverse and cover a broad range of soil types. The report of Soil Fertility of Tanzania by Mowo et al (1993) revealed the following classes to be dominant in the region; high altitude plateau with medium to heavy textured soils with low to moderate fertility and the tropical mountains with clayey soils of low to moderate fertility. The district of Mbozi where much of the fieldwork was undertaken covers an area of 3858 km^2 with a population of 446, 339 at a density of 115.7/km^2. About 82.6% of the population living in rural areas where agriculture is the main occupation (City population, 2020). The majority of rural inhabitants engage in crop farming or mixed farming where they keep livestock, including large and small ruminants and chickens. The main crops that seem to be a source of income in the region are Maize, coffee, banana, and beans. Maize and beans being a source of food as well.

Figure 1 shows the map of Africa locating Tanzania. An extrapolated region of Songwe showing the two study areas of Mbozi and Momba districts. Within Mbozi and Momba, the map shows the wards of villages where the fieldwork was conducted between September and December.

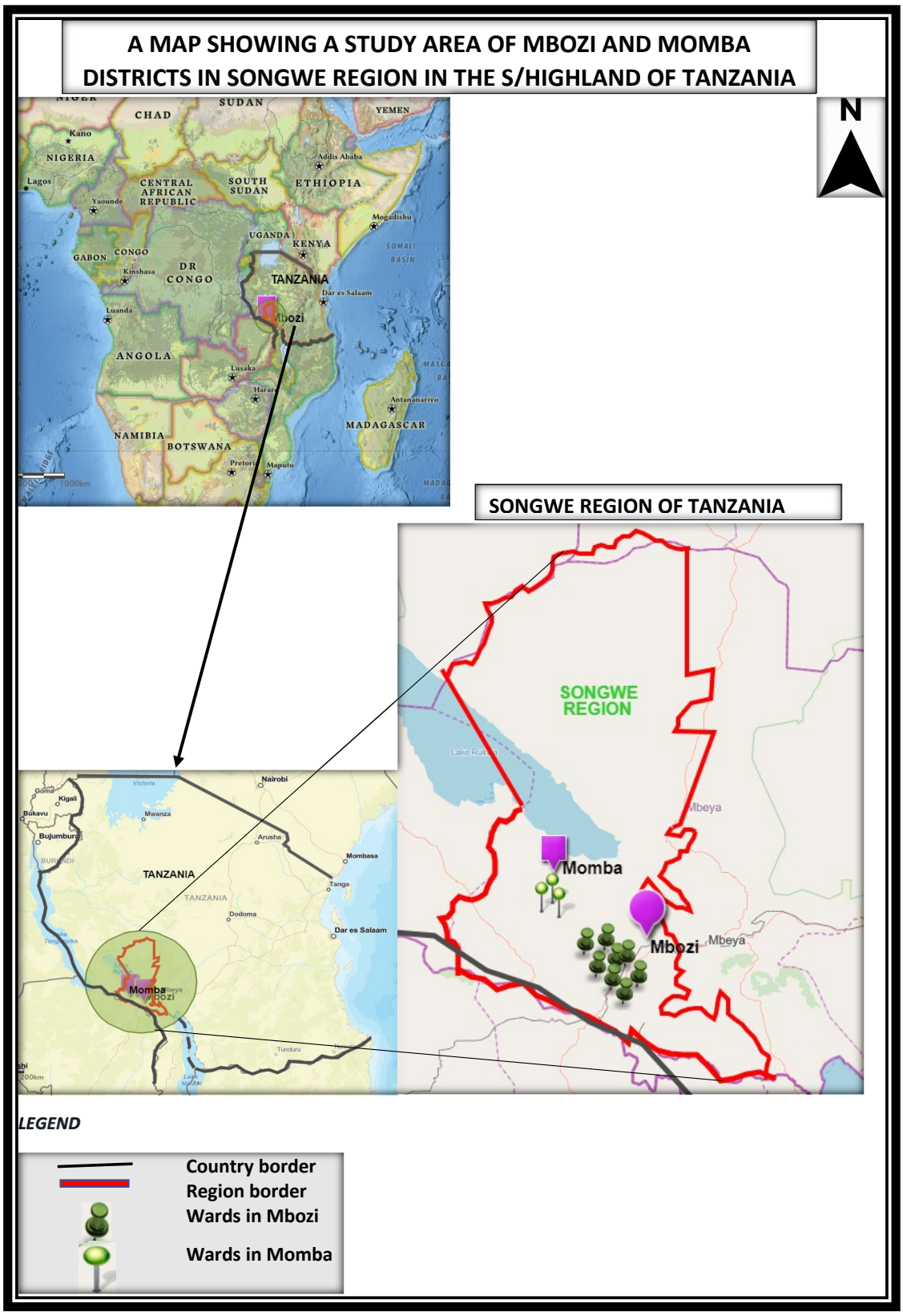

Figure 1 A map of Tanzania with an extrapolated region of Songwe showing the study areas of Mbozi and Momba districts.

2.2 Data collection and analysis

2.2.1. Data collection

Three groups of respondents were interviewed. The first group consisted of smallholder maize farmers. The second was a group of agro-dealers who supply agricultural inputs to maize farmers in the two districts. The last group was composed of extension workers serving the districts. The two districts of Mbozi and Momba were selected in consultation with TAMASA project supervisors and coordinators from CIMMYT and TARI, respectively. The interviews were guided by closed and open questions presented in the form of ODK collect questionnaires, a software for data collection that replaces paper forms. Fieldwork started from September to December 2019. The fieldwork was planned during this period of the year purposely to visit farmers as they prepare for the growing season and experience the first few months of the season (November and December). Before the fieldwork, a workshop (Fig. 2) was conducted in Vwawa town in Mbozi by CIMMYT and UYOLE research team to reflect on TAMASA project activities. This was an excellent opportunity to liaise with extension workers as key collaborators during fieldwork that followed the workshop.

Fieldwork started by interviewing farmers in 8 villages of Mbozi and 3 villages of Momba district. Farmers were selected through extension agents and interviewed about their nutrient management practices. To investigate further on management practices, farmers were asked to describe their household size, labour distribution, types of crops grown, cropping systems, and history. Furthermore, farmers were asked other questions specific about the field they grew maize last season of 2018. Questions about weeding practices, pest and disease management, planting density and time, fertilizer use, and harvest were asked. In the situation where a farmer had more than one maize fields, one field was selected in consultation with the farmer. The selection of the field based on the following criteria; nearest to the homestead, the biggest maize field, field which most fertilizers was used, the highest yielding/lowest yielding or for other reasons that deemed important to the farmer.

The area of selected maize field was also measured by the help of GPS coordinates using ODK collect software. The measurement was used to compare the actual size of the field against farmer estimations.

Agro dealers' interviews were conducted in two business-centres; Vwawa and Mlowo in Mbozi district; both located along the main road that leads to the Tunduma border with Zambia, the TANZAM highway. Agro dealers were randomly visited at their shops to find out about prices, packages, and types of commonly available fertilizers, seeds, and herbicides. Later common seed packages (5kg) were bought and weighed to check weight variation and the number of seeds contained in a pack of 5 kg. The information collected through interviews with agro-dealers was to be used to inform the MNM app design on the commonly available fertilizers, seeds and their prices.

Questionnaire interviews with extension workers were conducted in the same villages as farmers, most of the time at the end of the day after farmers' interviews. Extension worker

interviews aimed at collecting information on their working experience with farmers, their readiness to use the DSTs, and the kind of advice they provide to farmers regarding maize fertilizer use. Information collected was used to inform the MNM app on the mode of interaction with farmers, the ideal time to advise farmers and the usability of the app.

All three groups of respondents, farmers (102), agro-dealers (15), and extension agents (20), were interviewed in the Swahili language, the national language of Tanzania. The responses were recorded in English.

Table 1 Characteristics of a farm household in Mbozi and Momba districts of Songwe region (n=73 for Mbozi and n=29 for Momba district)

Characteristics	Mbozi (%)	Momba (%)
Gender		
male	67	83
female	33	17
Household size(mean=6)		
<4	14	11
4-8	67	72
>8	19	17
Landholding(ha)		
< 1	27	10
1-2	36	14
> 2	37	76

The table shows that interviewed farmers in Momba generally had larger landholdings. This seemed to reflect that the proportion of land set aside for maize production is probably large.

Some interesting photos taken in the field study area of Mbozi and Momba are presented in figure 2.

2.2.2. Data Analysis

Responses in the form of closed and open-ended answers from farmers and agro-dealers were compiled and analyzed using Microsoft Excel 2016. Data from the closed and open-ended answers in extension worker interviews were summarized and qualitatively analyzed by its content. In addition to descriptive statistical analysis by Microsoft Excel, qualitative information in the form of narrative based on personal observation during fieldwork is also given under the "Result" chapter of this report.

A: One of the households during field trips in Nzoka village in Momba district

B: A typical outdoor housing structure(boma) for cattle where manure is collected from

C: Spot-application of manure in Chimbuya village

D: A workshop with extensionists on MNM app in Vwawa-Mbozi (2019)

E: Agroshop in Halungu village

F: A farmer buying and transporting fertilizer by using motorcycle(boda-boda) -Msia village

Figure 2. Interesting photos were taken during fieldwork in Mbozi and Momba

3. Results

This chapter is organized in three sections; the first section 3.1 discusses the farming practices that have an impact on fertilizer use efficiency in their chronological order in the growing season. After presenting the findings of each farming practice, the implications for the app advisory are discussed immediately afterwards. The second section 3.2 and third section 3.3 present findings on agro-dealers and the extension workers respectively. At the end of section 3.2 and 3.3, the implications for the App advisory are discussed under the sub-section Implication for MNM app design.

3.1. Farmer Management Practices

3.1.1 Preparation before the start of the growing season

Farmer' preparation for the rainy season begins in September and October. Based on my observation, some farmers cleared their land by burning crop residues on the farm as they prepared for ploughing or hand hoeing. Others simply let their cattle feed on the residues in the farm before ploughing and hand-hoeing. 75% of farmers worked their farms by ploughing or hand hoeing depending on the size of their maize fields. During this time, farmers also started buying planting materials chiefly seeds and basal fertilizers. Most farmers buy basal fertilizer and seeds first and then later in the season buy top-dressing fertilizer and other inputs. Hybrid seeds and basal fertilizers are stored in the homes waiting for the rainy season to start. On the field near the homestead of farmers who own a few livestock, one notices heaps of manure being allocated across the maize field.

Buying hybrid seeds, basal chemical fertilizer, and spreading manure in the fields were not the only preparation practices. Farmers who could not afford to buy hybrid seeds at the beginning of the season collected local variety seeds by selecting seeds that look healthy from their previous harvest or from the neighbors who had "a good harvest" in the last season.

The implication for MNM app design: Timing of advice provision with MNM app and crop residue management.

As the description above shows: MNM app advice on what types of fertilizer to buy should begin way back, in early September, for the farmer to plan effectively for the rainy season. This means that, field advice can be given from the time farmer harvest, and that the app should have options for already bought inputs in order to be relevant.

Crop residue management practices: how a farmer manages their crop residues impacts N and P nutrient cycling; Leaving crop residues on the field after harvest improves soil fertility (Bakht et al., 2009). Studies by other researchers also show that maintaining crop residues on the field increase crop productivity by reducing soil nutrients losses (Shah et al., 2003,Shafi et al., 2007). Without soil cover soil nutrients are lost through leaching and erosion. Therefore, the App should ask how farmer managed their crop residues in the previous season. For instance, whether residues were incorporated back into the field during ploughing or burnt or fed to animals.

3.1.2 Time of planting and sowing practice

When rainfall delays at the beginning of the season farmers are inclined to sowing their maize seeds in dry days and wait for the rainfall to come, but most farmers usually sow during the first rains which start in early to mid-November. About 29% of interviewed farmers reported that they planted between mid to end of November(first rains) (Fig. 3). A sizeable number of farmers about 41% did not seem to keep records of their planting dates.

Based on field observation, sowing practices were of two types; one practice, which most farmers followed, was plough-sowing: seeds are placed in the furrow behind the plough. This kind of sowing practice saves the farmer time and labour. However, plough-sowing makes it difficult for a farmer to make a uniform plant spacing between and within rows across the field. Combining seeds and basal fertilizer during planting became even more difficult. A second common practice in the area was the use of hand hoes to make planting holes on tilled land. After working the soil, hand hoes are used to make sowing holes in the fields. In the process of this practice, seeds were placed in the holes and covered with soil. In the second type of practice, when there was adequate rainfall, the chances of applying basal fertilizer at planting were high if the farmer decided to.

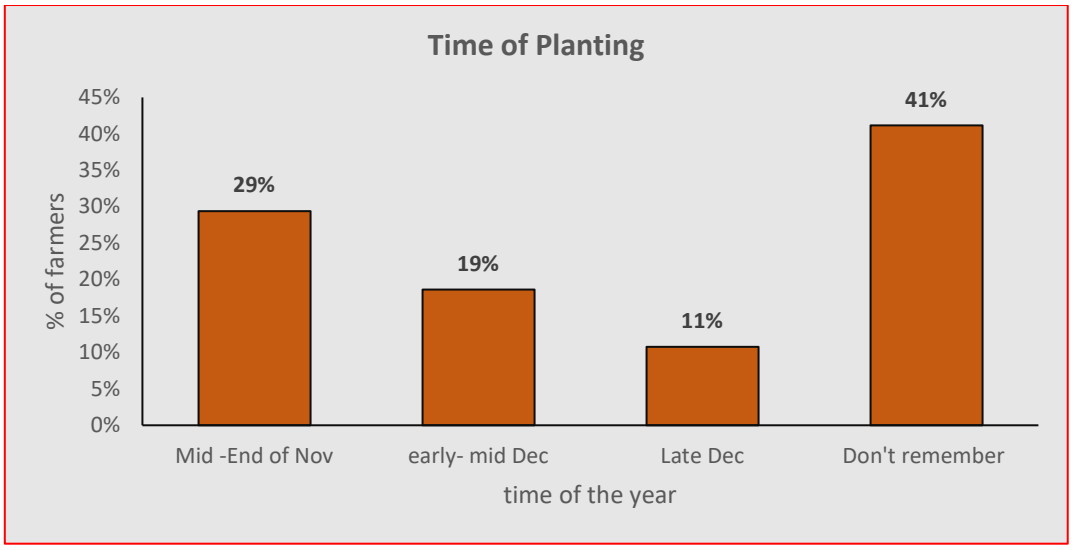

Figure 3. Sowing times Mbozi and Momba; About 30% of farmers started sowing their maize seeds between 15th and 30th November. This time is considered a period of first rains.

The implication for MNM app design: Incorporating dry planting advice into the app.

As the description above shows that, sometimes due to rainfall onset delays, farmers are forced to sow and then wait for the rains to come(dry-planting). In such situations, the MNM app can advise the farmer to apply basal fertilizer later, immediately after seed emergence when the soils are moist. Moisture in the soil increase mineralization and uptake of nutrients by the crop roots Alam (1999).

Late planting for reasons other than rainfall variability, and lack of resources like seeds in the beginning of the growing season is undesirable. Planting date as a variable is important to

include in the MNM app for evaluating yield. Since delayed planting is more likely to decrease yield in maize production(Ekeleme et al.,2009). Also farmers should be encouraged to keep records of planting dates.

3.1.3. Seeds, Seed rate and Planting density

The farmer questionnaire included 2 questions on the used maize variety; 41% of farmers used hybrid seed PANNAR 691, 14% TEMBO -SC719, 16% used local seeds and 29% used other varieties (Figure 4). Besides, the use of hybrid and local seeds, farmers also reported that they used recycled seeds from their maize harvest; this implies that farmers do not invest in new hybrid seeds. The recycled seeds are called “marudio” in the Swahili language. Farmers are aware that marudio produces less compared to new hybrid seeds, but are forced to use marudio when they do not have enough money to buy new hybrid seeds. Farmers in Nzoka and Makua villages claimed that PANNAR hybrid seeds (PAN 691) and SEEDCO (Tembo 719) performed better than other hybrid seeds when used as "marudio."

47% of farmers planted two seeds per hole regardless of seed type and planting; they used this high seeding rate as security against germination failure due to insect pests and drought.

Tillage methods seem to determine planting density. For example, if ploughing was done at the time of sowing, then the crop density becomes high per area as seeds are placed along the furrow made by an ox-drawn plough, without any actual measurement of the row to row and in-row distances. For example, 31% of farmers reported using a 60cm distance from furrow to furrow. In the other case, where hoe-sowing was employed, and if the farmers decided to follow the extensionist advice, they used 75x25cm as planting space. From my observation, most farmers do not consciously follow the planting density recommendation indicated on the label of the seed packages of their choice. However, not all seed packs have this information.

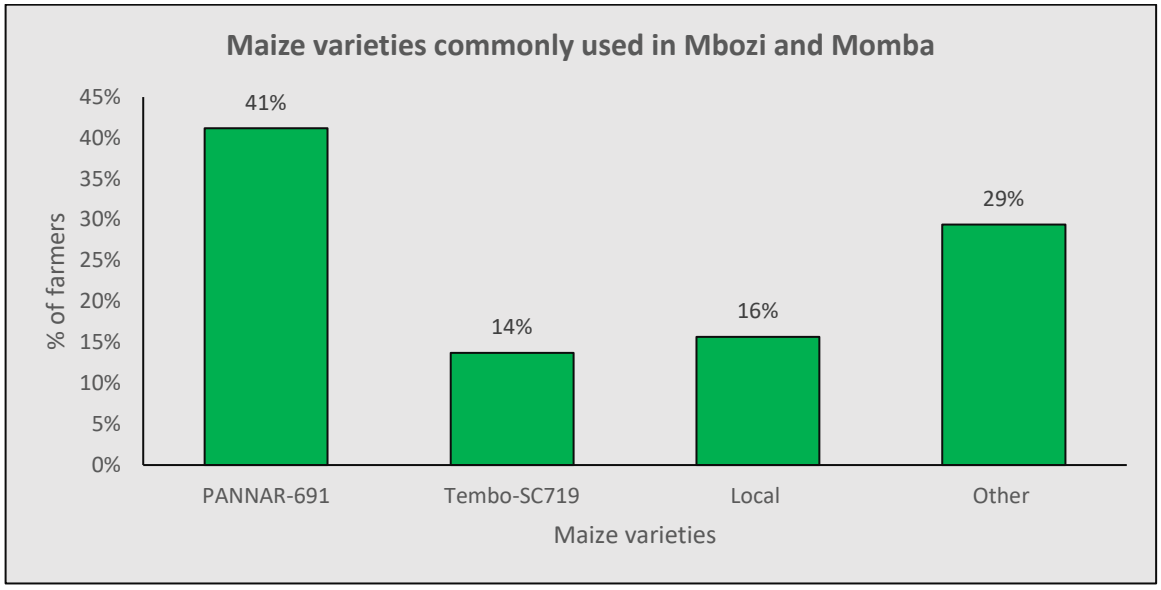

Figure 4: Popular maize seed varieties in Mbozi and Momba districts and the most bought varieties over the past two consecutive growing seasons 2017 and 2018 respectively.

Seed choice and planting density: Implication for MNM app design.

Too low or too high plant density will reduce yield. For example, too high plant density reduces resources required per plant, especially during silking (Valadabadi and Farahani (2010) causing a substantial decrease in yield. In the traditional system described above, farmers plant maize seeds behind the plough without following recommended plant spacing resulting in high plant density, which consequently might affect their yield. Therefore, it is might be more practical for the MNM advisory app to advice on planting density when hand hoes or other sowing techniques beside plough were used.

Recycled and local seeds: The MNM app may include an option for recycled or local seeds. Farmers reported that they used either local seeds or recycled seeds(marudio) in the times when could not afford to buy hybrid seeds.

3.1.4. Manure Use

Manure application

A few months before the beginning of the rainy season, cattle manure is spread across the fields. Two practices of manure application were observed in the region (Fig. 5). In the first practice, manure was uniformly spread across the field, which is only possible when there is plenty of manure, the field is relatively small and closer to home. In another practice (spot-application of manure), farmers applied only on spots in the field where maize seeds will be sown during ploughing or hand hoeing.

In the course of spot- application of manure some farmers used manure replacing inorganic fertilizer like DAP at planting. However, further discussion with farmers during interviews revealed that some farmers also used both manure and inorganic fertilizer(E.g. DAP) during planting.

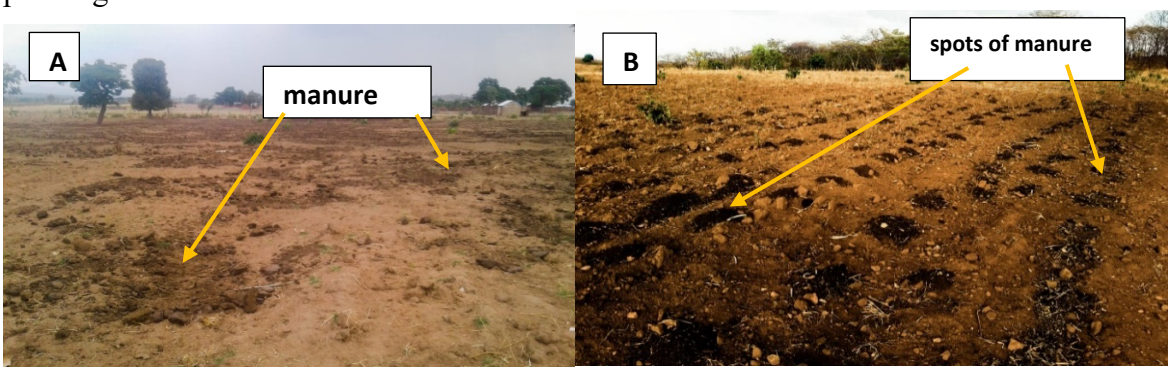

Figure 5. A: Manure was spread across the maize field before ploughing B: By spot- application practice, a handful of manure was placed on the holes ready for sowing at the beginning of the rainy season (Myunga village-Tanzania, photo taken in early Nov.2019 during field trips)

Manure distribution on the farm

Maize fields allocated far from homestead received no to little manure compared to fields around the home. It was also observed that farmers used the available manure mostly on fields that grew crops that had higher returns than maize. For example coffee in Mbozi District.
A quote below from the farmer interviews offers insights on why farmers avoided to allocate manure to the afar fields;

> *"A 49 years old woman in Chimbuya village was asked why she did not use manure in her maize field which was a bit distanced from the homestead. She responded that it was cumbersome to collect manure from the cowshed also known as "boma la ng'ombe" and transport them to the maize fields far from home; Additional constraint she described was the high cost associated with transportation of manure to fields allocated far away from home".*

The above quote from the farmers and findings on manure distribution suggest that distance to home may determine the use of manure if available. And since manure use is generally low (Fig.7.) application methods (spreading or spot-applications) are relatively important for understanding effects of manure on yield. The number of livestock owned by farmers was not a very good indication of manure used as 53% of farmers who owned cattle never used manure in their maize fields (Fig.7).

3.1.5. Manure and fertilizer storage

Storage of manure raises a question of manure quality; I observed that farmers left manure within the "boma" where cattle sleep during the night or heap it just outside boma without covering or storing in sheds. The "bomas" or cowsheds are without a roof (Fig.6), making manure N subject to volatilization and leaching in the dry and wet season, respectively.

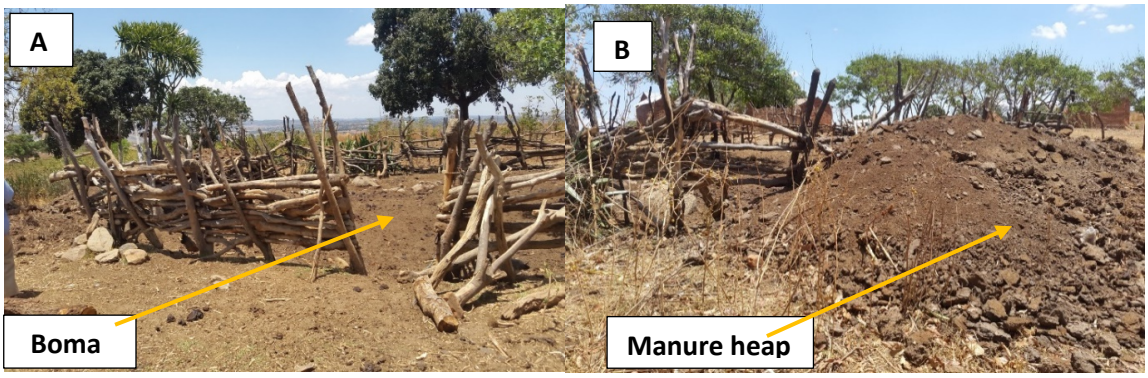

Figure 6: **A**: Cowshed(boma) in Makua village-Mbozi District [taken during field trips in October 2019). **B**: A heap of uncovered cow manure piled up outside the cowshed 'boma.'

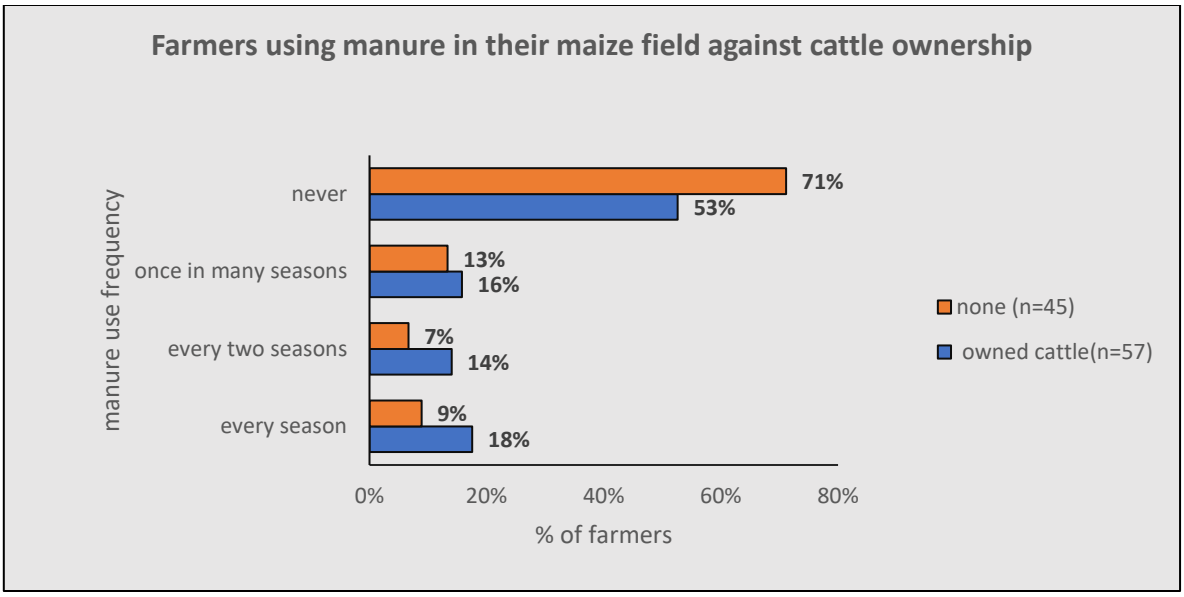

Figure 7. Cattle ownership against manure use in Mbozi and Momba

Scaling up the use of manure: Implication for MNM app design

A prolonged manure application could contribute to the overall improvement of soil fertility as it tends to raise the soil organic matter (Ding et al.,2012); Soil organic matter will consequently improve the structure of the poor soils. Combining cattle manure and inorganic fertilizer in cereal production is likey to increase grain yield (Guo et al.,2016). Other research studies for example by Vanlauwe et al (2006) showed that crop responses to applied N fertilizers decreased with the field's distance to the homestead. This suggests that fields near the homestead might have relatively higher levels of organic matter than far fields that did not receive organic fertilizer like manure. Another study by Tittonell et al (2007) also found that sandy homefields of maize had higher N and P recovery than sandy outfields. Therefore, a combination of manure and fertilizer use will probably increase crop yields due to the higher response to applied N and P fertilizer.

MNM app should advise farmers to use manure only if the manure was not used in other crops and yet available. However, further investigations need to be done in the study area on how farmers at the farm level arrive at decisions on the allocation of limited resources like manure in crop production. There are possibly more explanations as to why farmers make certain choices over the use of limited resources in crop production.

Manure storage and quality: Another area that needs further investigation is the storage of manure for better quality. It was observed in the field that the small amout of available manure was poorly stored. A study done by Chikowo et al (2004) in sandy soils of Zimbabwe reported N uptake was depressed following the application of poor-quality cattle manure. They also found that even large quantities of poor-quality manure had poor residual effects when measured in subsequent seasons. Therefore, before advising farmers to use manure in their maize fields. The questions about manure availability, quality and manure allocation as a limited resource, need to be investigated further.

3.1.6. Inorganic fertilizer use

Basal fertilizer

Findings on basal fertilizer application revealed that about 36% of farmers applied P fertilizer at planting while 40% did not use any P fertilizers at planting (Fig.8). About 15% of farmers applied DAP fertilizer when the maize plant had reached 5-8 leaves growth stage (Fig. 8). This suggested that DAP fertilizer was applied a bit late in the area against the known fact that P fertilizer such as DAP has to be supplied to the plant at earlier stages. 9% of farmers applied DAP as top-dressing fertilizer at seed emergence(Fig. 8). In Chimbuya village, farmers reported that the application of DAP fertilizer at seed emergence rather than at planting was due to delay of rainfall onset at the beginning of a season. Other reasons for the late application of DAP were more associated with financial constraints faced by smallholder farmers; I found that farmers were not able to buy basal fertilizer at the beginning of the season in November unless they sell their maize from the previous season in December when the price is a bit high on the market. Other farmers argued that it was more economical to apply DAP/NPK later at seed emergence to avoid wastage of fertilizer placed next to seeds that do not germinate.

Topdressing fertilizer

4% of interviewed farmers did not apply any top -dressing fertilizer, while 96% applied top-dressing fertilizer at least once. Topdressing was dominated by both single and split application of nitrogen fertilizers, mainly UREA (57.8% of farmers applied UREA last season). The first application of top-dressing fertilizer was categorized as a single N application. Figure **9.a.** shows how farmers applied N fertilizers at different stages of maize growth as the first application. 38% of farmers did not split their N fertilizer application (Fig 9.b.). The main reasons they give as to why the single application of top-dressing fertilizer and not split application are; split application requires more labour and more resources, that means one will need to hire manpower twice for spilt application and need to buy more fertilizers. The small budget allocated to the purchase of fertilizer force farmers to buy low quantity which is more unlikely to be effective if it split. Farmers had many fields to manage, which demanded most of their time and other resources.

The 62% of interviewed farmers split the application of N fertilizer, thus applying twice before harvest, the first application is either at 5-6 leaves, knee height, waist height or chest height. However, most farmers applied when maize crops have at least 8-10 leaves at first N fertilizer

application (See Fig.9.a). And for a second N fertilizer application, the majority applied when the maize plants are either at 8-10 leaves or tasselling(See Fig.9.b).

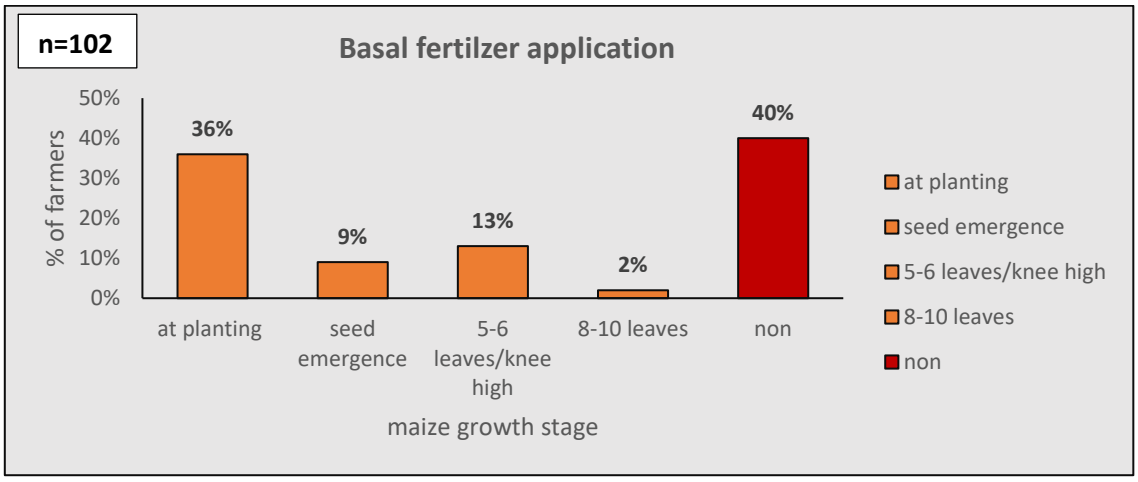

Figure 8. Timing of DAP and UREA fertilizer application in Mbozi and Momba

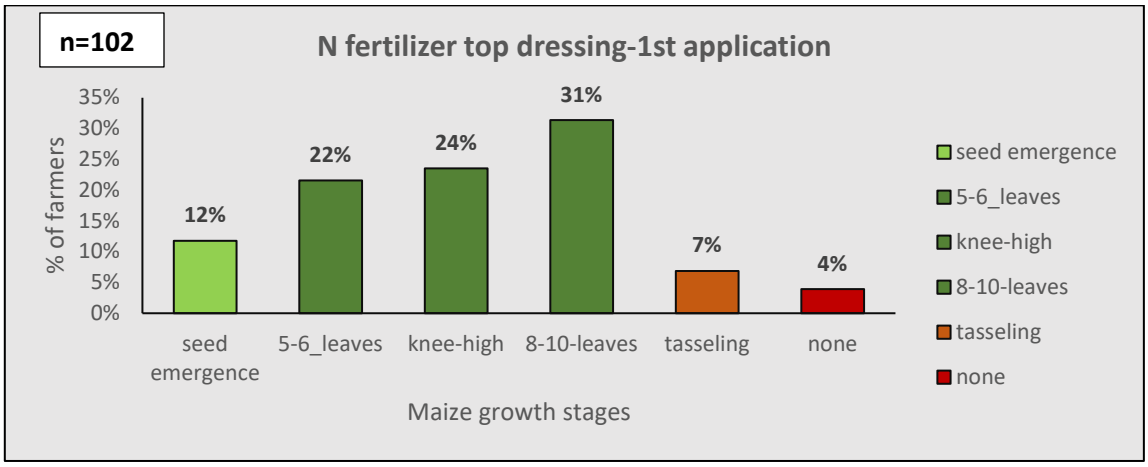

Figure 9. a: First application of N fertilizer at different stages of Maize growth (represents the difference in timing of N fertilization)

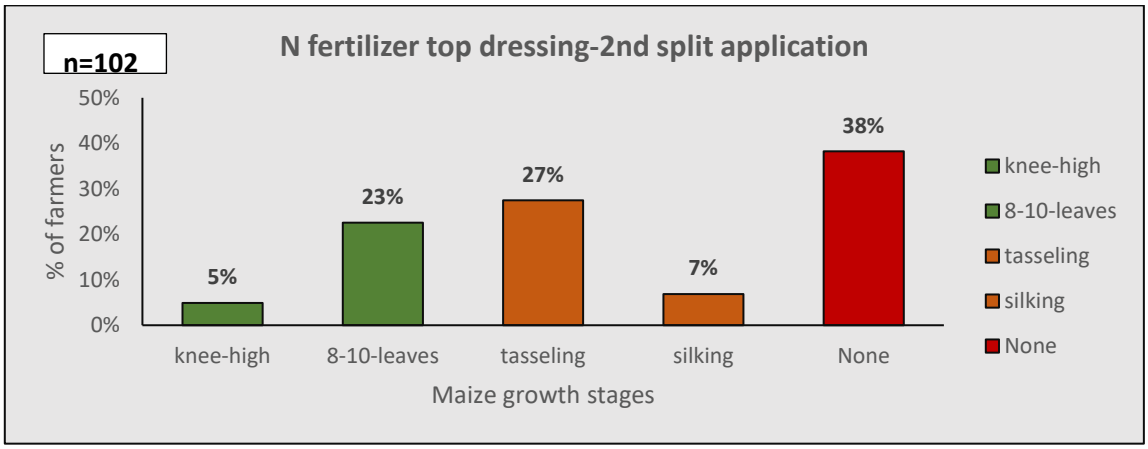

Figure 9. b: Second application of N fertilizer at different stages of Maize growth (represents the difference in timing of N fertilization)

Scope to improve the timing of both P and N fertilizer: Implication for MNM app

Timing of basal fertilizer application: MNM app can advise farmer to apply P fertilizer at planting if the farmer did not apply any for reasons other than lack of rainfall at planting. Supply of adequate P fertilizer at early stages of maize growth is more likely to increase yield(Grant et al.,2005).

Dry-planting: If a farmer did not apply P fertilizer due to delayed onset of rainfall. MNM App should be able to advise farmer to do so immediately at seed emergence.

Split application of N fertilizer: A study by Abbasi et al. (2013) showed that split application of N fertilizer application gave more grain yield in rainfed maize than a single application N fertilizer. MNM advisory app should advise farmer to make a timely split application of N-fertilizer like UREA, where the first application should be at least 5 to 6 leaves and the second application at 8 to 10 leaves. Moreover, in a situation where farmers do no have enough N-fertilizer, then make a single application at 7-8 leaves.

3.1.7. Weeding

About 44% of interviewed farmers weed twice before harvest. Farmers reported that the first weeding is either at pre-emergence or after seed emergence when maize is at 2-3 leaves. The second weeding is just before top dressing fertilizer application. Weeding was done by both mechanical(hand hoeing) and chemical means(herbicides).

The use of herbicides is increasingly becoming a common practice among farmers to minimize the time spend on weeding by hand hoeing; Also, during open question interview, farmers argued that weeding by using herbicides was way cheaper than paying for mechanical weeding when labour is hired. However, a sizeable number of farmers still prefer mechanical weeding by hand hoes. In both cases of weeding hired labour or family, labour is used to implement the activity.

Timely weeding: Implication for the app

Timely weeding will increase crop competitiveness. Both pre-emergence, early weeding after seed emergence and weeding before top-dressing fertilizer application are desirable. For example, weeding before topdressing application of fertilizer will reduce the possibility of weed-crop competition for nutrients(Di Tomaso, 1995). Therefore, MNM app can advise farmers to continue with these weeding practices.

3.1.8. Cropping systems

Crop rotation and patchy intercropping were the common cropping patterns in the area; crops involved in rotation were maize, groundnuts, and beans, most of the time the sequence follows either a consecutive two seasons or a season of maize, followed by groundnuts or beans, and then start over again. In recent years beans and Groundnuts(Fig. 10) are more used in the rotation due to their high price in the market. Other reasons for crop rotation were; in the low

season, when farmers do not have enough cash to spend on agro-inputs like fertilizers, they opted for crops like groundnuts and beans, which demanded less inorganic fertilizer compared to maize. For example, farmers applied only DAP to beans and no fertilizer was applied to groundnuts.

Intercropping includes growing different crops in small patches; here, maize is grown in the more substantial portion of the field as a mono stand; on one side next to maize, you find a small portion of finger millets. On the other side, farmers grow groundnuts either alone or mixed with beans.

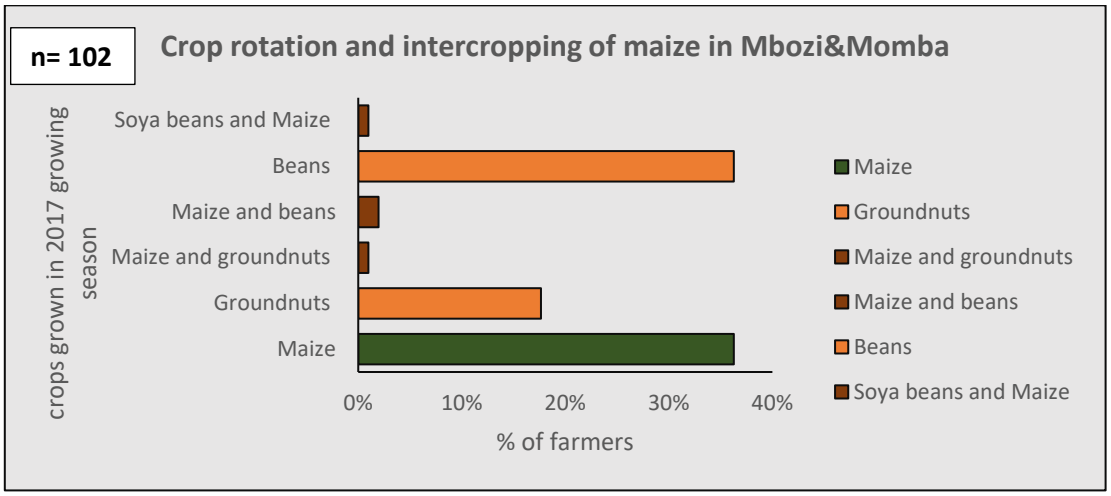

Figure 10: **Crops grown in the field before maize was grown in 2018 growing season. Cereals and legumes are the most common crops in both crop rotation and intercropping patterns.**

Crop rotation: Implication for MNM app design.

Figure 10 shows that crop rotation of maize and legumes(beans and groundnuts) is predominant in the area. Including grain legumes like beans and groundnuts in the crop rotation contribute a great deal of N nutrient into soil N pool due to their N fixation ability(fixing free Nitrogen in the air into the soil) Franke et al(2018). The fixed N in soil is taken up by the subsequent crop like maize in subsequent seasons. Therefore, the MNM app should advise farmers to continue practising crop rotation of maize and leguminous crops like groundnuts and beans.

3.1.9. P and K deficiency

To make the MNM app advice more effective, levels of P and K deficiencies were investigated. P and K deficiency information will be incorporated into the app to tell whether the farmer should use DAP or NPK as basal fertilizer at planting. In determining possible deficiencies of P and K photos showing deficiency symptoms were presented to farmers(Fig.11) Farmers were asked whether P and K deficiency symptoms were observed during the maize growing season. Then farmers commented if they had observed P and K deficiency symptoms in their maize or not.

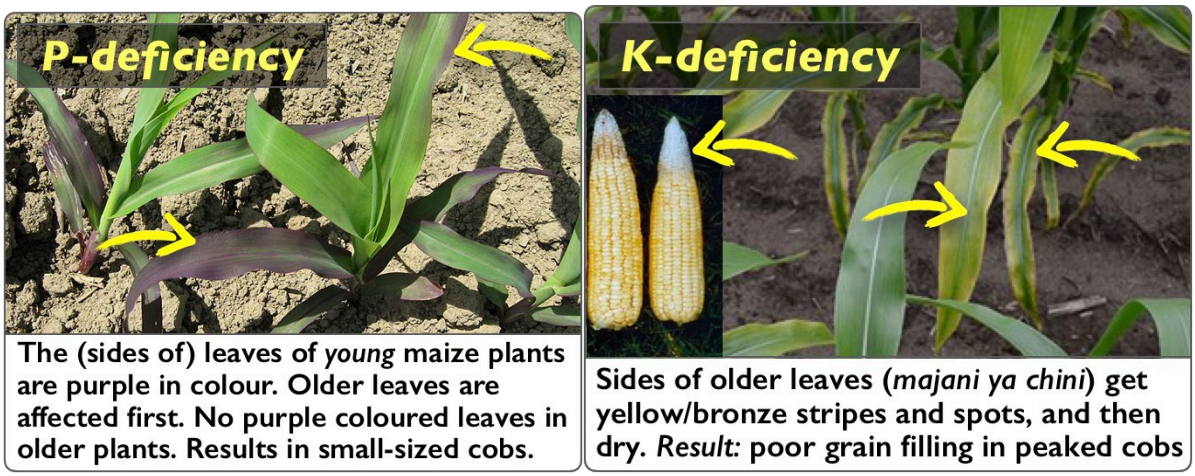

Figure 11. P and K deficiency symptoms in Maize.

20% and 23% of interviewed farmers observed P and K deficiencies respectively (Fig.12). One possible explanation for the low observation of P deficiency was the use of fertilizer P in consecutive seasons. Since P is considered the least immobile nutrient in the soil its recovery (P uptake by the crop) in the first year could be as low as 10 % to 30% of applied fertilizer P such as DAP and becoming more available to subsequent crops (Roberts, 2008). In a maize-beans crop rotation farming system, farmers in Mbozi and Momba districts applied DAP fertilizer every season to both beans and maize. This continuous application of P fertilizer on the same field alone could have been an important factor for solving P deficiency in the maize field. However, surprisingly still a significant P deficiency was observed in the area.

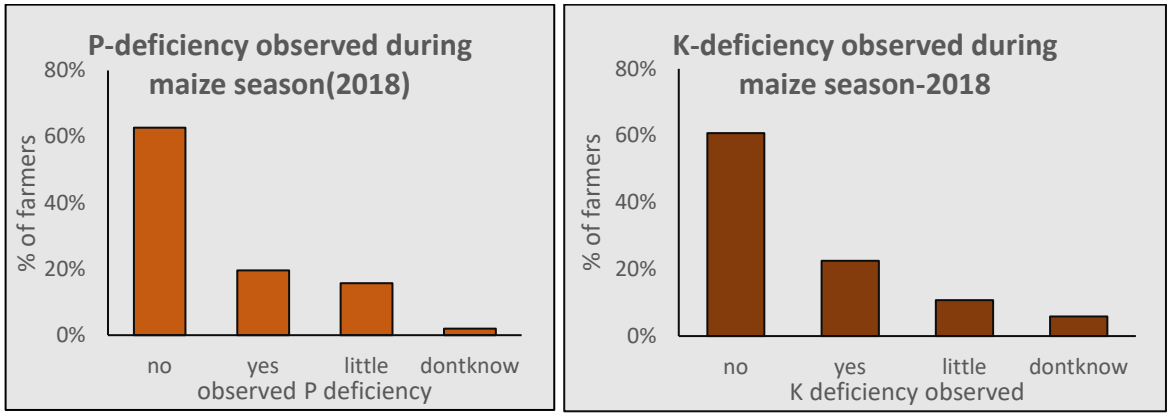

Figure 12: Observed P and K-deficiency in the maize fields.

Basal fertilizer and the P fertilizer residual effects: Implication for MNM app

DAP and NPK: the App will recommend the use of DAP when P deficiency was observed. And NPK when there was an observed K deficiency.

P fertilizer use in crops other than maize: A question about the trend of P fertilizer use in crops other than maize in previous seasons is essential in MNM advisory app. MNM app should not just focus on previous maize but rather on other crops as well since farmers in Mbozi and Momba applied DAP when crops like beans were grown in maize crop rotation. Such a question will reflect the residual effects of P fertilizer applied in previous seasons. Residual effects of P fertilizer applied in previous seasons is a factor to consider when advising the farmer over how much P fertilizer should use.

3.1.10. Pest and disease

There is a low incidence of pests and diseases in the area since 92% of farmers did not report any severe loss of harvest due to pests and disease. Low pest and disease incidence might have been the result of crop rotation and intercropping as typical practices in the area. Based on farmers' responses during interviews, crop rotation and intercropping have been practised for a long time in Mbozi and Momba (over the past 15 years).

The implication for MNM app.

The MNM should only ask whether pest and diseases severely affected their maize yield. If any try to contact a nearby extension agent for more advice.

3.1.11. Harvesting

To realize how much yield a farmer gets from investing in agro-inputs such as fertilizer and seeds, information about harvesting was necessary. Farmers were asked how much grain maize (bags of grain maize) they get per field. This was rather difficult as most farmers put their maize harvests from different fields together in one place. Farmers did not seem to remember how many bags of maize were harvested from a particular maize field when they have more than one maize fields. However if a farmer hired a shelling machine for her maize harvest, they keep records of how many bags("*gunia"* a commonly used term for a bag of 110kg of maize grain*)*were shelled per field. With shelling machine was much easier for the farmer to record the number of bags harvested per field as the machine is set up on the farm during harvest.

I also observed that if a particular maize field was dedicated to household consumption, a farmer would not pay much attention to the field. However, if the field were intended to produce maize for sale, the farmers keep much of the records of her investment, and keen about the final harvest.

Separation of harvest from different maize fields: Implication for MNM app.

One straightforward recommendation for the MNM advisory app is that farmers should be advised to keep their maize grain harvest separate from field to field. It should also ask the number of "gunia", a rather common measurement for grain maize in the area. Information about whether the farmer hired a shelling machine at harvest will somehow lead to the precision of an exact number of "gunia" shelled per field. Separation of harvest allows the

farmer to draw a more precise conclusion over how much yield was obtained per field versus inputs used and makes evaluation of changes in farming practices easier.

3.2. Agrodealer practices

The interviews with agro-dealers were intended to collect information about prices, packages, and types of commonly available fertilizers, and seeds. This kind of information will be incorporated into the MNM app design to generate advice for farmers.

Agro dealers were randomly visited in their shops. Most of agro-input shops are in small towns of Vwawa and Mlowo in the Mbozi district, and a few were found in Tunduma town in Momba. Farmers from rural areas of Mbozi travel either to Mlowo or Vwawa to buy seeds and fertilizers. However, few small shops selling agro-inputs were found in villages like Halungu, Chimbuya, and Mpemba.

90% per cent of agro-dealers responded that stocking of fertilizer and seeds from leading distributors of fertilizer and seed companies was never a problem. They usually stock in September and October, which is only a few months before the start of the growing season in November. In September and October, the demand for seeds and basal fertilizer by farmers is high, as farmers start buying these inputs to prepare for the growing season that starts in November. Agro dealers grouped farmers in two main categories; farmers who buy seeds, basal fertilizer and top-dressing fertilizer in bulky all at once, which represent about 30% of farmers in the districts. The other group represents about 70% of the farmer population buy seeds and basal fertilizer first, and then later in the season around January and February top-dressing fertilizers.

Interestingly, 'agro-dealers' in Mbozi and Momba districts were not only selling agro-inputs to farmers but also provided farmers with information on fertilizer rate application and timing, quality seeds, and other farming management skills. When agro-dealers asked about what sources of information they draw on this advice offered to farmers, some responded that Seed and Fertilizer companies trained them. Agro-dealers were trained at least once in a year, especially in September and October right before the beginning of the growing season. For example, the YARA fertilizer company conducts seminars for agro-dealers covering topics like proper maize fertilization, fertilizer, and seed management skills like storage at least twice a year.

3.2.1 Fertilizer and seed prices, agro-dealers as MNM app user: Implication for MNM app.

Seed variety and prices: Incorporates all the available common maize seed packs (2 kg per pack) in the area into MNM app. Incorporate the common prices for 2 kg pack of maize seeds.

Fertilizer type, quantity and price: incorporate all commonly available P fertilizers such as DAP and NPK into the app. Commonly available fertilizer quantities in packs (E.g. 25kg and 50 kg bags of fertilizer) should be incorporated into the app as well with their associated prices. Such options in the app will make it easier for the farmer to choose what works best for them depending on their income and field conditions.

Agro dealers as a potential MNM app user: the description above shows that agro-dealers play a role in advice provision not so different from that of extensionist. Therefore, the design of MNM should be robust to accommodate users like agro-dealers.

3.3. Extension agent advisory practices

Extension workers advised farmers in most farming activities from land preparation to harvest and post-harvest practices. Therefore, information about their experience working with farmers was essential to inform the mode of interaction between the MNM and the farmers. Extensionist reported that farmers mostly sought advice on the type and use of fertilizer and seed varieties in maize production. Farmers started enquiring information from extension agents about which maize seed varieties and fertilizer to buy in the months before the start of the growing season. Midway the season, farmers started asking about N fertilizer recommendation rates and types.

To provide farmers with necessary information as they prepare for the start of the season extension workers organized farmer group meetings. At farmer group meeting general information on best-farming management practices was shared. Other information from the government (E.g. subsidies on fertilizer or introduction of novel technology), agro-inputs companies (seed and fertilizer company), and finance companies were communicated during these meetings as well. Through farmer group meetings extension agents met a good number of farmers at the same time, which saved them time and resources, but the information offered at these meetings was rather general and never tailored to specific needs of the farmer nor field conditions.

Through organized farmer groups facilitated by extensionists especially in Nzoka village, farmers were able to buy fertilizer on credit from fertilizer companies. Another interesting observation about these farmer groups was that they received training on fertilizer use through workshops organized by fertilizer companies with the full support of their respective extension workers.

3.3.1 Extensionists experience in advice provision: Implication for MNM app

Timing of MNM advice provision and farmer home visits. The experience of extensionists in advice provision informs that advice with MNM app to farmers should begin as early as possible before the start of the growing season. Preferably in the period between harvest and before the start of the season. Since the MNM app will be designed to provide a farmer with field-specific advises, extensionist' home visits can be used to reach out to farmers.

Farmer group meetings: Extensionists organize farmer group meetings before the beginning of the season. Such meetings could be used as space to raise awareness of the importance of DST such as MNM app in improving farming practices.

4. Discussion and Conclusion

4.1. Farmers

The data collected through the ODK survey (n=102) showed that there is room for farmers to improve their management practices to reach a higher yield in maize production. The most critical area that needs much improvement is the timing of application of both basal and top-dressing fertilizers. In Mbozi and Momba, farmers seemed to either apply too late or too early of both basal and top-dressing fertilizers (Figure 8). P fertilizer like DAP must be inadequate supply at the early stages of plant growth to increase crop productivity and consequently the grain yield (Grant et al.,2005). A study by Abbasi et al. (2013) showed that split application of N fertilizer application gave more grain yield in rainfed maize than a single application N fertilizer. Another study conducted in Ethiopia by Tadesse et al(2013) also proved that Split application of N fertilizer at an early stage of maize plant and knee-high gave higher grain yield compared to the full application of N fertilizer. Generally, it is more likely that if P fertilizer such DAP or NPK are supplied at the time of planting combined with split/single application of N fertilizer will increase grain yield of maize. However, there are other farming practices that farmers already do to improve their maize yield, which include maize rotation with leguminous crops like groundnuts and beans (N-fixing crops). Maize-legume rotation might contribute to overall soil fertility by increasing organic matter content in the soil. A maintained soil organic content is more likely to improve crop productivity (Bakht et al.,2009) and consequently the yield.

Scaling up the use of MNM app: For effective delivery of the advice generated by MNM app to farmers incorporating a native language seemed to be an important element. Majority of farmers speak and understand the Swahili language better than English. By incorporating Swahili into the MNM app design is more likely to enhance the communication with farmers and minimize the possibility of misinterpretation of inputs and output of the app. The study by Tata and McNamara (2016) also showed that using local languages in decision support tools is important for effective communication with farmers.

Co-designing of MNM app: Incorporating farmer experience in the design of the DTSs like MNM app increases the relevance of such tools to the context of the farmer. Relevance is one of the factors that contribute to the uptake and use of such apps by farmers, however other factors such as usability (easy to use), cost-effectiveness and performance of the app are important (Rose et al., 2016). The design of the MNM app is on one hand of the tasks that lie ahead of this work. But on the other hand, is the upscaling of MNM app as DST by farmers. Thus, my thesis project which will be a continuation of this work will focus on investigating the adoption of MNM app among maize growers in the Southern Highlands of Tanzania.

However, to fully understand the constraints in its entirety that hinder farmers from adopting the best fertilizer use or best nutrient management practices in general. A detailed investigation of social-economic factors at the farm level and field conditions need to be done in the area. There could be more factors as to why farmers are stuck in the current practices of fertilizer application that short time studies such as this or M.Sc. thesis projects may tend to miss or overlook.

4.2. Agro dealers

There is growing evidence in rural Africa that a growing network of agro-dealers is bringing agro-inputs in this case fertilizers and seeds, even closer to rural farmers making it ever accessible. The findings revealed that agro-dealers play a role in advice provision to farmers. In Mbozi agro-dealers provided farmers with both agro-inputs and the information on the use of those agro-inputs. For example, agro-dealers provided farmers with information on fertilizer application rate and types. The study by Kelly et al (2003) also showed that the role of agro-dealers in the agriculture sector is twofold; that is, they provide farmers with both materials and technical knowledge of agricultural inputs. This experience of agro-dealers suggests that agro-dealers could also use the MNM app to enhance their role in the provision of advice to farmers on the proper use of fertilizer and other agro-inputs. However, care should be given so that MNM does not become a generic tool rather than specific as its initial purpose. Since agro-dealers are rarely seen on the ground accompanying farmers in their fields, which might render it difficult to obtain such information like field size and soil conditions. Unless otherwise MNM app design is simplified to accommodate such scenarios.

4.3. Extension workers

The role of extension workers in advice provision to farmers is obvious. Through questionnaire interviews that were conducted during this internship work revealed how important it is to consider the advice provision experience of extensionists in the design of DST like MNM app. The interview results show that extensionists have different strategies in reaching out to farmers. Extensionists use mostly home visits to reach individual farmers but also organize group farmer meetings. In the group farmer meeting usually organized at the beginning of the season, farmers get general information and advice as they prepare for the growing season. Since M-N-M will be designed as a field-specific advisory app, it might work very well with home visits where an individual farmer is attended. But at a group farmer meeting, MNM app might prove ineffective as it requires a more specific input before it generates advice. However, group farmer meetings could serve as social spaces for raising awareness among farmers on the use of such decision support tools in their farming management aimed at increasing yield. Despite the limitation of MNM as was in the case of group meetings, still, the MNM is more likely to improve the quality of advice provided to the farmer during home visits. Since its development is based on scientific evidence and uses field-specific inputs, the generated advice might be more relevant to farmers context.

In conclusion, there are nutrient management practices that farmers do are undoubtedly established on rational grounds, but with the change of time and circumstances, I might argue that some of these practices especially fertilization should change. To improve the fertilization practices, I envision the role of MNM app, which provides a farmer with advice on proper nutrition practice. Of course, the app is not the end, but rather a means to an end. Thus, it cannot be without its limitations. For example, its use by farmers who never used technological gadgets like smartphone might be difficult; it is also more likely to be usefully to the individual farmer rather than a group of farmers. The later might prove a challenge

when an extensionist tries to reach farmers as a group to minimize time and resources spent on home visits to individual farmers. But with the help of well-trained extensionists, MNM app can help to elevate the conversation we carry with farmers on the importance of proper and balanced nutrition of maize. The design of the app which reflect the farmer context could sensitize farmers towards a proper fertilization plan for their maize to increase yield.

Reference

Abbasi, M. K., Tahir, M. M., & Rahim, N. (2013). Effect of N fertilizer source and timing on yield and N use efficiency of rainfed maize (Zea mays L.) in Kashmir–Pakistan. *Geoderma, 195-196*, 87-93. doi:10.1016/j.geoderma.2012.11.013

Alam, S. M. (1999). Nutrient uptake by plants under stress conditions. *Handbook of plant and crop stress, 2*, 285-313.

Bakht, J., Shafi, M., Jan, M. T., & Shah, Z. (2009). Influence of crop residue management, cropping system and N fertilizer on soil N and C dynamics and sustainable wheat (Triticum aestivum L.) production. *Soil and Tillage Research, 104*(2), 233-240.

Belay, K., & Abebaw, D. (2004). Challenges facing agricultural extension agents: A case study from south-western Ethiopia. *African Development Review-Revue Africaine De Developpement, 16*(1), 139-168. doi:10.1111/j.1467-8268.2004.00087.x

Cairns, J. E., Hellin, J., Sonder, K., Araus, J. L., MacRobert, J. F., Thierfelder, C., & Prasanna, B. (2013). Adapting maize production to climate change in sub-Saharan Africa. *Food Security, 5*(3), 345-360.

Chikowo, R., Mapfumo, P., Nyamugafata, P., & Giller, K. E. (2004). Maize productivity and mineral N dynamics following different soil fertility management practices on a depleted sandy soil in Zimbabwe. *Agriculture, Ecosystems & Environment, 102*(2), 119-131. doi:10.1016/j.agee.2003.08.009

Di Tomaso, J. M. (1995). Approaches for improving crop competitiveness through the manipulation of fertilization strategies. *Weed Science, 43*(3), 491-497.

Ding, X., Han, X., Liang, Y., Qiao, Y., Li, L., & Li, N. (2012). Changes in soil organic carbon pools after 10 years of continuous manuring combined with chemical fertilizer in a Mollisol in China. *Soil and Tillage Research, 122*, 36-41.

Ekeleme, F., Chikoye, D., & Omoigui, L. O. (2009). Planting date and cultivar effects on grain yield in dryland corn production. *Agronomy Journal, 101*(1), 91-98.

Franke, A. C., van den Brand, G. J., Vanlauwe, B., & Giller, K. E. (2018). Sustainable intensification through rotations with grain legumes in Sub-Saharan Africa: A review. *Agric Ecosyst Environ, 261*, 172-185. doi:10.1016/j.agee.2017.09.029

Grant, C., Bittman, S., Montreal, M., Plenchette, C., & Morel, C. (2005). Soil and fertilizer phosphorus: Effects on plant P supply and mycorrhizal development. *Canadian Journal of Plant Science, 85*(1), 3-14.

Guo, L., Wu, G., Li, Y., Li, C., Liu, W., Meng, J., . . . Jiang, G. (2016). Effects of cattle manure compost combined with chemical fertilizer on topsoil organic matter, bulk density and earthworm activity in a wheat–maize rotation system in Eastern China. *Soil and Tillage Research, 156*, 140-147.

Ichami, S. M., Shepherd, K. D., Sila, A. M., Stoorvogel, J. J., & Hoffland, E. (2018). Fertilizer response and nitrogen use efficiency in African smallholder maize farms. *Nutrient Cycling in Agroecosystems, 113*(1), 1-19. doi:10.1007/s10705-018-9958-y

Kelly, V., Adesina, A. A., & Gordon, A. (2003). Expanding access to agricultural inputs in Africa: a review of recent market development experience. *Food Policy, 28*(4), 379-404. doi:10.1016/j.foodpol.2003.08.006

Mowo, J., Floor, J., Kaihura, F., & Magogo, J. (1993). Review of fertilizer recommendations in Tanzania. *Part, 2*, 25-29.

Roberts, T. L. (2008). Improving nutrient use efficiency. *Turkish Journal of Agriculture and Forestry, 32*(3), 177-182.

Rose, D. C., Sutherland, W. J., Parker, C., Lobley, M., Winter, M., Morris, C., . . . Dicks, L. V. (2016). Decision support tools for agriculture: Towards effective design and delivery. *Agricultural Systems, 149*, 165-174. doi:10.1016/j.agsy.2016.09.009

Sanchez, P. A. (2002). Soil fertility and hunger in Africa. *Science, 295*(5562), 2019-2020.

Shafi, M., Bakht, J., Jan, M. T., & Shah, Z. (2007). Soil C and N dynamics and maize (Zea may L.) yield as affected by cropping systems and residue management in North-western Pakistan. *Soil and Tillage Research, 94*(2), 520-529.

Shah, Z., Shah, S., Peoples, M., Schwenke, G., & Herridge, D. (2003). Crop residue and fertiliser N effects on nitrogen fixation and yields of legume–cereal rotations and soil organic fertility. *Field Crops Research, 83*(1), 1-11.

Tadesse, T., Assefa, A., Liben, M., & Tadesse, Z. (2013). Effects of nitrogen split-application on productivity, nitrogen use efficiency and economic benefits of maize production in Ethiopia. *International Journal of Agricultural Policy and Research, 1*(4), 109-115.

Tata, J., & McNamara, P. (2016). Social Factors That Influence Use of ICT in Agricultural Extension in Southern Africa. *Agriculture, 6*(2). doi:10.3390/agriculture6020015

Tittonell, P., Muriuki, A., Klapwijk, C. J., Shepherd, K. D., Coe, R., & Vanlauwe, B. (2013). Soil Heterogeneity and Soil Fertility Gradients in Smallholder Farms of the East African Highlands. *Soil Science Society of America Journal, 77*(2), 525-538. doi:10.2136/sssaj2012.0250

Tittonell, P., Vanlauwe, B., Leffelaar, P. A., Rowe, E. C., & Giller, K. E. (2005). Exploring diversity in soil fertility management of smallholder farms in western Kenya.

Agriculture, Ecosystems & Environment, 110(3-4), 149-165. doi:10.1016/j.agee.2005.04.001

Tittonell, P., Zingore, S., van Wijk, M. T., Corbeels, M., & Giller, K. E. (2007). Nutrient use efficiencies and crop responses to N, P and manure applications in Zimbabwean soils: Exploring management strategies across soil fertility gradients. *Field Crops Research, 100*(2-3), 348-368. doi:10.1016/j.fcr.2006.09.003

Valadabadi, S. A., & Farahani, H. A. (2010). Effects of planting density and pattern on physiological growth indices in maize (Zea mays L.) under nitrogenous fertilizer application. *Journal of Agricultural Extension and Rural Development, 2*(3), 040-047.

Vanlauwe, B., Kihara, J., Chivenge, P., Pypers, P., Coe, R., & Six, J. (2010). Agronomic use efficiency of N fertilizer in maize-based systems in sub-Saharan Africa within the context of integrated soil fertility management. *Plant and Soil, 339*(1-2), 35-50. doi:10.1007/s11104-010-0462-7

Vanlauwe, B., Tittonell, P., & Mukalama, J. (2006). Within-farm soil fertility gradients affect response of maize to fertiliser application in western Kenya. *Nutrient Cycling in Agroecosystems, 76*(2-3), 171-182. doi:10.1007/s10705-005-8314-1

Wortmann, C. S., Senkoro, C., Cyamweshi, A. R., Kibunja, C., Nkonde, D., Munthali, M., . . . Kaizzi, K. (2018). Maize-nutrient response functions for Eastern and Southern Africa. *Agronomy Journal, 110*(5), 2070-2079.